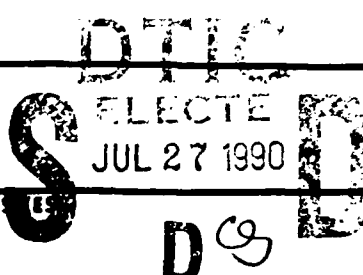


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13. ABSTRACT (Maximum 200 words) During the course of this research, several trips were made to LEAR (the Low Energy Antiproton Ring) in Geneva. On one trip, the feasibility of using a thick beryllium degrader to slow antiprotons enough to permit capture was established. On another trip, approximately 1000 antiprotons were captured and held for about ten minutes. Subsequently, a completely new apparatus was designed using a proper superconducting magnet, and a beam line at LEAR was designed for the mass measurement. At the end of the research period, all apparatus and arrangements were complete for making the measurement of the antiproton inertial mass.				
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University of Washington

Final Report

Antiproton Studies in Penning Traps

AFOSR-86-0069

1 February 1986 - 31 December 1988

Gerald Gabrielse

**FINAL TECHNICAL REPORT FOR AFOSR 62-5241****A. Summary of Completed Project**

The 3 years of research went well, much as proposed to AFOSR. We were allocated 1% of the antiprotons available at the Low Energy Antiproton Ring (LEAR) in Geneva to do our tests. In May 1986 we went to LEAR. In a 1 day run, we used the time-of-flight apparatus to measure the energy distribution of 21 MeV antiprotons after they were slowed in a thick beryllium degrader. As we had anticipated, enough antiprotons were present to consider catching some antiprotons in an ion trap.

In July 1986, we returned to LEAR for a second 1 day run. We were able to catch of order 1000 antiprotons from a single burst of  $10^8$  antiprotons from LEAR. We held several antiprotons as long as 10 minutes. Under better vacuum conditions which we are now arranging, prospects for holding antiprotons long enough to do precision mass measurements are now excellent.

Over the last year we have obtained a proper superconducting magnet in which to conduct the mass measurements. A completely new apparatus was designed and constructed with the goal of making a comparison of the proton and antiproton masses at an accuracy of 1 part per million, which is an increase in precision over current measurements by more than an order of magnitude. We are now experimenting with protons. We also designed a beam line at LEAR for the mass measurement. This beamline is solely for our use and is now under construction.

At the end of the grant period we were positioned to begin to measure the inertial mass of the antiproton, which is the first major goal of this research.

Gerald Gabrielse

**B. List of Publications Acknowledging APOSR Support**

1. "Prospects for Experiments with Trapped Antiprotons," G. Gabrielse, K. Helmersen, R. Tjoelker, X. Fei, T. Trainor, W. Kells, H. Kalinowsky; in *Proceedings of Workshop on Low Energy Antiprotons*, Ed. by L. Pinsky and B. Bormar, Fermilab (1986).
2. "First Capture of Antiprotons in a Penning Trap: A KeV Source," G. Gabrielse, X. Fei, K. Helmersen, S.L. Rolston, R. Tjoelker, T.A. Trainor, H. Kalinowsky, J. Haas, and W. Kells; *Phys. Rev. Lett.* 57, 2504 (1986).
3. "Penning Traps, Masses and Antiprotons," G. Gabrielse; in *Fundamental Symmetries*, edited by R. Klapisch, p. 59 (Plenum, New York, 1987), (Lecture presented Sept. 29, 1986, Erice, Italy).
4. "High Voltage Switching for In-flight Capture of KeV Antiprotons in a Penning Trap," X. Fei, R. Davisson and G. Gabrielse; *Rev. of Sci.* (in press).
5. "First Capture of Antiprotons in an Ion Trap and the Possibility of Antihydrogen," G. Gabrielse; in *Proceedings of Workshop on Cooling Condensation and Storage of Hydrogen*, edited by J. Bahns, Univ. of Dayton (1987).
6. "Cyclotron Motion in Penning Trap Microwave Cavity," L.S. Brown, G. Gabrielse, J. Tan, K.C.D. Chan; submitted to *Phys. Rev. A*.
7. "First Antiprotons in an Ion Trap," G. Gabrielse, X. Fei, K. Helmersen, S.L. Rolston, R. Tjoelker, T.A. Trainor, H. Kalinowsky, J. Haas, W. Kells; in *Proceedings of AFI Workshop and Symposium on the Physics of Low Energy, Stored and Trapped Particles*, Stockholm, Sweden (1987).
8. "First Antiprotons in an Ion Trap," G. Gabrielse, X. Fei, K. Helmersen, S.L. Rolston, R. Tjoelker, T.A. Trainor, H. Kalinowsky, J. Haas, W. Kells; in *Proceedings of the 8th International Conference on Laser Spectroscopy*, Åre, Sweden (1987).
9. "Antihydrogen Production," G. Gabrielse, L. Haarsma, S.L. Rolston, W. Kells; in *Proceedings of the 8th International Conference on Laser Spectroscopy*, Åre, Sweden (1987).
10. "Collisions with Trapped Antiprotons," G. Gabrielse; in *Proceedings of the XV International Conference on the Physics of Electronic and Atomic Collisions - XV ICPEAC*, Brighton, UK, Ed. by H.B. Gilbody, W.R. Newell, F.H. Read and A.C.H. Smith (1987).
11. "Antihydrogen Production with Cold Trapped Plasmas," G. Gabrielse, L. Haarsma, S. Rolston, W. Kells; *Phys. Lett. A* 129, 1 (1988).
12. "Self-Shielding Superconducting Solenoid Systems," G. Gabrielse, J. Tan, *J. Appl. Phys.* 63, 10 (1988).

**C. Colloquia and Invited Talks Acknowledging AFOSR Support****1985**

July 1 Gordon Conference on Atomic Physics (invited talk)  
Oct. 9 University of California at Berkeley (physics colloquium)  
Oct. 23 State University of New York at Stony Brook (physics colloquium)  
Oct. 24 IBM (Yorktown, New York)  
Oct. 25 Columbia University (physics colloquium)  
Dec. 9 Harvard University (physics colloquium)  
Dec. 11 Fermi National Accelerator Laboratory (physics colloquium)

**1986**

Jan. 28 University of Guelph (physics colloquium)  
Jan. 29 University of Western Ontario (physics colloquium)  
Mar. 3 TRIUMF (physics colloquium)  
Mar. 27 Institute for Seattle Area Physics and Math Teachers  
June 9 International Conference on Quantum Electronics XIV, San Francisco (invited lecture)  
Sept. 23 International School of Physics with Low Energy Antiprotons: Fundamental Symmetries (invited tutorial lecture)  
Oct. 24 SPS Invited Lecture, Optical Society of America Meeting Seattle, WA  
Nov. 13 University of Nebraska (physics colloquium)

**1987**

Jan. 8 Cluster Ion Conference, San Francisco (invited lecture)  
Jan. 20 Brandeis University (physics colloquium)  
Jan. 22 Brookhaven National Laboratory (physics colloquium)  
Jan. 23 Columbia University (physics colloquium)  
Mar. 19 Argonne National Laboratory (particle physics colloquium)  
Apr. 20 American Physical Society Meeting, Crystal City, VA (invited lecture)  
May 5 Northwestern University (physics colloquium)  
May 7 University of Missouri-Rolla, Distinguished Visiting Professor Program (invited lecture)  
May 20 American Physical Society Meeting, Boston, MA (invited lecture)  
June 15 AFI Workshop and Symposium on Low Energy Particles, Stockholm, Sweden (invited lecture)  
June 22 Laser Spectroscopy Conference, Åre, Sweden (invited lecture)  
July 22 International Conference on the Physics of Electrons and Collisions (ICPEAC), Brighton, England (invited lecture)  
Oct. 1 Syracuse University (physics colloquium)  
Nov. 2 Harvard University (physics colloquium)  
Nov. 13 Yale University (physics colloquium)  
Dec. 1 International Conference on Low Energy Antimatter, Karlsruhe, Germany (invited lecture)

1988

Feb. 2 Calvin College (physics colloquium)  
 Feb. 3 Notre Dame (physics colloquium)  
 Feb. 4 University of Chicago (physics colloquium)  
 Feb. 25 Amherst College (physics colloquium)  
 Feb. 26 University of Connecticut (physics colloquium)  
 Apr. 7 Pennsylvania State University (physics colloquium)  
 May 16 Third Conference on the Interaction Between Particle and  
 Nuclear Physics, Rockport, Maine (invited plenary lecture)  
 July 1 Symposium on the Hydrogen Atom at the Scuola, Normale Superiore  
 Pisa, Italy (invited lecture)  
 Sept. 6 IX European Symposium on Antiproton Interactions and Fundamental  
 Symmetries, Mainz, Germany (invited lecture)

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